# Dual Nature of Radiation

## Question1

**When a photosensitive material is illuminated by photons of energy 3.1 eV , the stopping potential of the photoelectrons is 1.7 V . When the same photosensitive material is illuminated by photons of energy 2.5 eV , the stopping potential of the photoelectrons is**

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**Options:**

A.

1.8 V

B.

1.4 V

C.

1.1 V

D.

1.3 V

**Answer: C**

## Solution:

When light hits a photosensitive material, electrons are released. The energy of the incoming light (photon) is used to release these electrons and provide them with some extra energy.

Einstein's photoelectric equation helps us understand this process:

$E_{\max} = h\nu - \phi_0$

- This means: the maximum energy of the emitted electrons equals the energy of the incoming photon minus the work function ($\phi_0$), which is the energy needed to release the electron.

The stopping potential ($V_0$) is linked to this energy by:

$eV_0 = h\nu - \phi_0$

or

$V_0 = \frac{h\nu}{e} - \frac{\phi_0}{e}$

First, use the given values for the first case:

For photon energy 3.1 eV and stopping potential 1.7 V:

$V_0 = 3.1 - \frac{\phi_0}{e}$

$1.7 = 3.1 - \frac{\phi_0}{e}$

To find the work function divided by $e$:

$\frac{\phi_0}{e} = 3.1 - 1.7 = 1.4$

So, $\frac{\phi_0}{e} = 1.4$ volt

Now, use this value for the second case:

For photon energy 2.5 eV:

$V_0 = 2.5 - \frac{\phi_0}{e}$

$V_0 = 2.5 - 1.4 = 1.1$ V

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# Question2

**Photons of energy 4.5 eV are incident on a photosensitive material of work function 3 eV . The de-Broglie wavelength associated with the photoelectrons emitted with maximum kinetic energy is nearly**

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**Options:**

A.

$10\text{Å}$

▪ B.

$5\overset{\circ}{A}$

C.

$20\overset{\circ}{A}$

D.

$15\overset{\circ}{A}$

**Answer: A**

## Solution:

The maximum kinetic energy

$$\mathrm{KE}_{\max} = E - \phi$$
$$\mathrm{KE}_{\max} = 4.5\mathrm{eV} - 3\mathrm{eV}$$
$$\mathrm{KE}_{\max} = 1.5\mathrm{eV}$$

The de-Broglie wavelength is,

$$\lambda = \frac{12.27}{\sqrt{KE_{\max}}}\overset{\circ}{A}$$
$$\lambda = \frac{12.27}{\sqrt{1.5}}\overset{\circ}{A} \Rightarrow \lambda \approx \frac{12.27}{1.2247}\overset{\circ}{A}$$
$$\lambda \approx 10.018\overset{\circ}{A}$$

The de-Broglie wavelength associated with the photoelectrons is approximately $10.02\overset{\circ}{A}$.

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# Question3

**The work functions of two photosensitive metal surfaces $A$ and $B$ are in the ratio $2:3$. If $x$ and $y$ are the slopes of the graphs drawn between the stopping potential and frequency of incident light for the surfaces $A$ and $B$ respectively, then $x:y=$**

**TG EAPCET 2024 (Online) 11th May Morning Shift**

**Options:**

A. $1:1$

B. 2 : 3

C. 4 : 9

D. 2 : 5

**Answer: A**

## Solution:

Given,

$\phi_A : \phi_B = 2 : 3 \Rightarrow \phi_A = 2k, \phi_B = 3k$

Using Einstein's photoelectric equation

$eV_0 = hv - hv_0$

where, $h =$ Planck's constant, $v =$ frequency of incident light

$v_0 =$ threshold frequency, $V_0 =$ stopping potential

$V_0 = \frac{h}{e}v - \frac{h}{e}v_0$

Now comparing Eq. (i) with $y = mx + C$

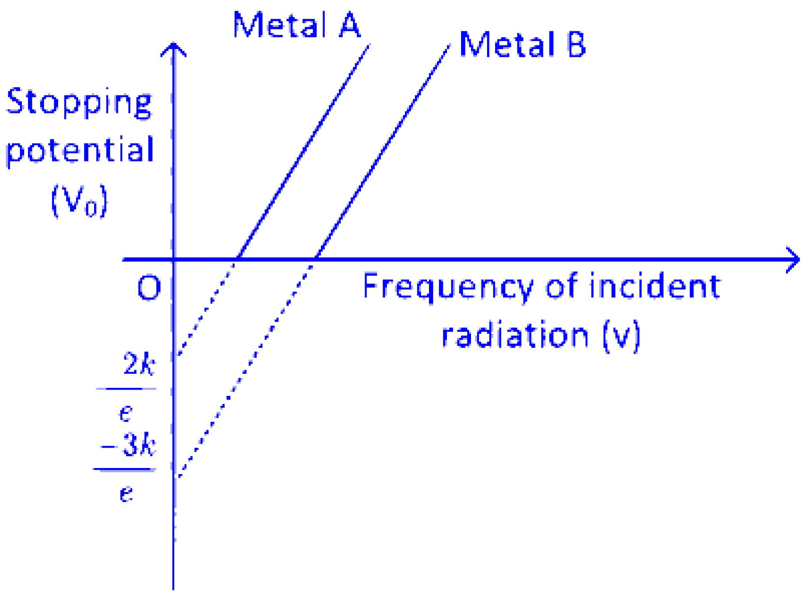
Here, slope $m = \frac{h}{e}$.

The slopes $x$ and $y$ of the graphs drawn between the stopping potential and the frequency of incident light for surfaces

$A$ and $B$ depend only on the constant $h$ and $e$ not on the work function of $A$ and $B$. So, $x$ and $y$ are the same for both metals.

$x = y = \frac{h}{e}$

Hence, $x : y = 1 : 1$

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# Question4

## Wave picture of light has failed to explain

## TG EAPCET 2024 (Online) 10th May Evening Shift

**Options:**

A. photoelectric effect

B. interference of light

C. diffraction of light

D. polarisation of light

**Answer: A**

## Solution:

The wave picture of light fails to explain the **photoelectric effect**.

The **photoelectric effect** is the phenomenon where electrons are ejected from a material's surface when it is exposed to light of certain frequencies. According to the classical wave theory of light, increasing the intensity of light (regardless of frequency) should increase the energy of emitted electrons. However, experiments show that there is a minimum threshold frequency below which no electrons are emitted, regardless of light intensity. Moreover, the maximum kinetic energy of the emitted electrons depends on the frequency of the incident light, not its intensity.

Albert Einstein explained the photoelectric effect by proposing that light consists of discrete packets of energy called photons. Each photon has an energy given by the equation:

$E = hf$

where:

$E$ is the energy of the photon,

$h$ is Planck's constant ($6.626 \times 10^{-34}$ Js),

$f$ is the frequency of the light.

Thus, only photons with enough energy (i.e., with frequency above the threshold frequency) can eject electrons, thereby providing a particle-like explanation for light, which is not accounted for by its wave-like nature.

In contrast, the wave picture of light successfully explains phenomena like **interference**, **diffraction**, and **polarization of light**. Interference and diffraction involve the superposition of light waves to produce patterns, and polarization relates to the orientation of light waves, all of which align with the wave nature of light.

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## Question5

**The efficiency of a bulb of power 60 W is $16\%$. The peak value of the electric field produced by the electromagnetic radiation from the bulb at a distance of 2 m from the bulb is** $\left(\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \mathrm{Nm}^2\mathrm{C}^{-2}\right)$

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**Options:**

A. $24\mathrm{Vm}^{-1}$

B. $16\mathrm{Vm}^{-1}$

C. $9\mathrm{Vm}^{-1}$

D. $12\mathrm{Vm}^{-1}$

**Answer: D**

## Solution:

Given:

Power of the bulb = 60 W

Efficiency = $16\%$

**Calculation of Actual Power:**

The actual power is determined by multiplying the efficiency with the total power:

$P = \frac{16}{100} \times 60 = 9.6\,\mathrm{W}$

**Intensity of Electromagnetic Radiation:**

The intensity, $I$, of the electromagnetic radiation is given by the formula:

$I = \frac{1}{2}\varepsilon_0 c E_0^2$

where:

$c$ is the speed of light.

$E_0$ is the peak electric field.

**Relation of Intensity with Power and Area:**

The intensity is also expressed as power per unit area:

- $I = \frac{\text{Power}}{\text{Area}} = \frac{P}{4\pi r^2}$

Equating the two expressions for intensity:

$\frac{P}{4\pi r^2} = \frac{1}{2}\varepsilon_0 c E_0^2$

Solving for $E_0^2$:

$E_0^2 = \frac{2P}{4\pi\varepsilon_0 c r^2}$

**Substituting the Known Values:**

$r = 2\,\text{m}$

$c = 3 \times 10^8\,\text{m/s}$

$\varepsilon_0 = \frac{1}{4\pi \times 9 \times 10^9}$

Substituting these values into the equation for $E_0^2$:

$E_0^2 = \frac{2 \times 9.6 \times 9 \times 10^9}{4 \times \pi \times \left(\frac{1}{4\pi \times 9 \times 10^9}\right) \times (3 \times 10^8) \times 2^2}$

Simplifying further:

$E_0^2 = \frac{2 \times 9.6 \times 9 \times 10^9}{4 \times 3 \times 10^8}$

$E_0^2 = 144$

Hence, the peak value of the electric field is:

$E_0 = \sqrt{144} = 12\,\text{V/m}$

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# Question6

**The work function of a photosensitive metal surface is 1.1 eV . Two light beams of energies 1.5 eV and 2 eV incident on the metal surface. The ratio of the maximum velocities of the emitted photoelectrons is**

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**Options:**

A. 3 : 4

B. 1 : 1

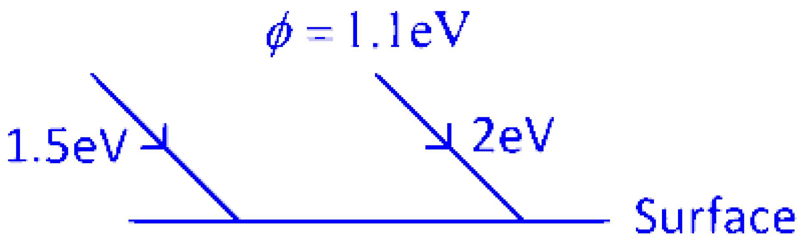
C. 2 : 3

- D. 4 : 9

**Answer: C**

## Solution:

Given,




Work function, $\phi = 1.1\text{eV}$

Using photoelectric equation for each incident radiation.

$E = \frac{1}{2}mv^2 + \phi$

where $E$ is energy of incident radiation $\frac{1}{2}mv^2$ = kinetic energy of photoelectron

$E_1 = \frac{1}{2}mv_1^2 + \phi$

$E_2 = \frac{1}{2}mv_2^2 + \phi$

From Eqs. (ii) and (iii)

$$\frac{v_1^2}{v_2^2} = \frac{E_1 - \phi}{E_2 - \phi}$$

$$= \frac{1.5 - 1.1}{2 - 1.1}$$

$$\frac{v_1^2}{v_2^2} = \frac{0.4}{0.9} \Rightarrow \frac{v_1}{v_2} = \frac{2}{3}$$

$v_1 : v_2 = 2 : 3$

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# Question7

**The de-Broglie wavelength of a proton is twice the de-Broglie wavelength of an alpha particle. The ratio of the kinetic energies of the proton and the alpha particle is**

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- **Options:**

A. 1 : 1

B. 1 : 4

C. 1 : 2

D. 1 : 8

**Answer: A**

## Solution:

Given, de-Broglie wavelength of proton $=2\times$ de-Broglie wavelength of $\alpha$-particle

de-Broglie wavelength in term of kinetic energy $E$ and mass $m$ is,

$\lambda=\frac{h}{\sqrt{2mE}}$

Now, $\quad \lambda_p=2\lambda_\alpha$

$\Rightarrow \quad \frac{h}{\sqrt{2mE_1}}=\frac{2h}{\sqrt{2(4m)E_2}}$

where $E_1$ and $E_2$ are KE respectively

$\frac{1}{\sqrt{E_1}}=\frac{1}{\sqrt{E_2}}$

$\therefore \quad \frac{E_1}{E_2}=\frac{1}{1}$

Ratio is 1 : 1

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# Question8

**If the de-Broglie wavelength of a neutron at a temperature of $77^{\circ}\mathrm{C}$ is $\lambda$, then the de-Broglie wavelength of the neutron at a temperature of $1127^{\circ}\mathrm{C}$ is**

**TG EAPCET 2024 (Online) 9th May Evening Shift**

**Options:**

A. $\frac{\lambda}{2}$

B. $\frac{\lambda}{3}$

C. $\frac{\lambda}{4}$

D. $\frac{\lambda}{9}$

**Answer: A**

## Solution:

Energy of neutron at temperature,

$T = \frac{3}{2} k_B T$

de-Broglie wavelength

$= \frac{h}{\sqrt{2mE}} \propto \frac{h}{\sqrt{2 \times m_n \times T}}$

Here, $T_1 = (273 + 77)\text{K} = 350 \text{ K}$

$T_2 = (273 + 1127)\text{K} = 1400 \text{ K}$

$$\therefore \frac{\lambda_2}{\lambda_1} = \frac{h}{\sqrt{2m_n \times 1400}} \times \frac{\sqrt{2m_n \times 350}}{h}$$

$$\lambda_2 = \lambda \times \frac{1}{2}$$

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## Question9

**If Planck's constant is $6.63 \times 10^{-34}$Js, then the slope of a graph drawn between cut-off voltage and frequency of incident light in a photoelectric experiment is**

**TG EAPCET 2024 (Online) 9th May Morning Shift**

**Options:**

A. $414 \times 10^{-15}$ Vs

B. $19.776 \times 10^{-15}$Vs

C. $2.198 \times 10^{-15}$Vs

D. $1.337 \times 10^{-15}$ Vs

**Answer: A**

▪ **Solution:**

The relationship between the cut-off voltage $V_0$ and the frequency $f$ of incident light in a photoelectric experiment is given by the equation:

$eV_0 = hf - \phi$

where:

$e$ is the elementary charge ($1.6 \times 10^{-19}$ C),

$h$ is Planck's constant ($6.63 \times 10^{-34}$ Js),

$\phi$ is the work function of the material.

Rearranging the equation provides:

$V_0 = \frac{h}{e} f - \frac{\phi}{e}$

The slope $m$ of the graph of $V_0$ versus $f$ is given by the factor of $f$, which is $\frac{h}{e}$.

Substituting the given values:

$m = \frac{h}{e} = \frac{6.63 \times 10^{-34} \text{ Js}}{1.6 \times 10^{-19} \text{ C}}$

Calculating this gives:

$m = \frac{6.63}{1.6} \times 10^{-15} \approx 4.14375 \times 10^{-15}$ Vs

Thus, the correct option is:

Option A: $414 \times 10^{-15}$ Vs

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# Question10

## The additional energy that should be given to an electron to reduce its de-Broglie wavelength from 1 nm to 0.5 nm is

## TS EAMCET 2023 (Online) 12th May Evening Shift

**Options:**

A. four times initial energy

B. thrice the initial energy

C. equal to the initial energy

- D. twice the initial energy

**Answer: B**

## Solution:

Given:

Initial wavelength: $\lambda_1 = 1 \text{ nm}$

Final wavelength: $\lambda_2 = 0.5 \text{ nm}$

According to de-Broglie's principle, the wavelength ($\lambda$) is given by:

$$\lambda = \frac{h}{p}$$

where $p$ (momentum) is related to the kinetic energy ($K$) by:

$$p = \sqrt{2mK}$$

This leads to the expression for the kinetic energy in terms of wavelength:

$$K = \frac{h^2}{2m\lambda^2}$$

where:

$p$ = momentum

$K$ = kinetic energy

$m$ = mass of the electron

$h$ = Planck's constant

**Initial Kinetic Energy:**

$$K_i = \frac{h^2}{2m(\lambda_1)^2} = \frac{h^2}{2m(1 \text{ nm } )^2}$$

**Final Kinetic Energy:**

$$K_f = \frac{h^2}{2m(\lambda_2)^2} = \frac{h^2}{2m(0.5 \text{ nm } )^2}$$

**Change in Kinetic Energy:**

The change in kinetic energy $\Delta K$ is calculated as:

$$\Delta K = K_f - K_i = \frac{h^2}{2m}\left(\frac{1}{(0.5)^2} - \frac{1}{1^2}\right)$$

Simplifying, we get:

$$\Delta K = 3\left(\frac{h^2}{2m}\right) = 3K_i$$

Thus, the additional energy required to halve the wavelength is **three times the initial energy**.

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## Question11

**The de-Broglie wavelength of an electron accelerated between two plates having a potential difference of 900 V is nearly**

**TS EAMCET 2023 (Online) 12th May Morning Shift**

**Options:**

A. 0.015 nm

B. 0.01 nm

C. 0.02 nm

D. 0.04 nm

**Answer: D**

## Solution:

The de Broglie wavelength of an electron, which is accelerated by a potential difference $V$, is calculated using the following formula:

$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE_k}}$

where $E_k = eV$ (with $e$ being the charge of the electron and $V$ the potential difference). This leads to:

$\lambda = \frac{h}{\sqrt{2meV}}$

By substituting the known values of $h$, $m$, and $e$ into the formula, we simplify it to:

$\lambda = \frac{1.23}{\sqrt{V}}$ nm

To find the de Broglie wavelength for a potential difference of 900 V, we calculate:

$\lambda = \frac{1.23}{\sqrt{900}}$ nm $= \frac{1.23}{30}$ nm

Thus, the de Broglie wavelength is approximately:

$\lambda = 0.04$ nm

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